# SPIDER 2 TESTS - RESPONSE OF TYPICAL WALL PANELS TO DEBRIS AND FRAGMENT IMPACT

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## ABSTRACT

As part of the U.S. Department of Defense Explosives Safety Board (DDESB) Project ESKIMORE, the Science Panel Impact Debris Evaluation and Review (SPIDER) test program has been planned to develop improved predictions for the hazards inside an exposed site (ES) from fragments and debris. Data collected includes the mass and velocity required for perforation of the test cross-section and characteristics of all debris produced inside the ES.

The 2004 SPIDER 1 test program tested the hazard from high-angle debris striking typical roof sections at terminal velocity. Similarly, the 2009 SPIDER 2 test program conducted at Redstone Arsenal tested the effect of debris and fragments impacting wall cross-sections. The wall response (e.g. penetration, deformation, spalling, breaching, perforation) to variable masses and velocities of spherical steel and concrete impactors was determined. Impact velocity and residual velocity of perforating fragments and ES debris were measured for each test.

A trajectory analysis was used to choose SPIDER 2 steel and concrete impactor characteristics consistent with the masses, initial potential explosion site (PES) debris velocities (< 3000 fps), and low launch angles (< $15^o$) that can critically impact walls at 500 to 3000 ft from the PES. Primary steel fragments, with initial velocities of < 5000 fps, were also included in the trajectory analysis.

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14. ABSTRACT
**As part of the U.S. Department of Defense Explosives Safety Board (DDESB) Project ESKIMORE, the Science Panel Impact Debris Evaluation and Review (SPIDER) test program has been planned to develop improved predictions for the hazards inside an exposed site (ES) from fragments and debris. Data collected includes the mass and velocity required for perforation of the test cross-section and characteristics of all debris produced inside the ES. The 2004 SPIDER 1 test program tested the hazard from high-angle debris striking typical roof sections at terminal velocity. Similarly, the 2009 SPIDER 2 test program conducted at Redstone Arsenal tested the effect of debris and fragments impacting wall cross-sections. The wall response (e.g. penetration, deformation, spalling, breaching, perforation) to variable masses and velocities of spherical steel and concrete impactors was determined. Impact velocity and residual velocity of perforating fragments and ES debris were measured for each test. A trajectory analysis was used to choose SPIDER 2 steel and concrete impactor characteristics consistent with the masses, initial potential explosion site (PES) debris velocities (< 3000 fps), and low launch angles (< 15o) that can critically impact walls at 500 to 3000 ft from the PES. Primary steel fragments, with initial velocities of < 5000 fps, were also included in the trajectory analysis.**

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The SPIDER test program is detailed including impactor, roof and wall target designs. Test results and analyses of results are presented for both SPIDER 1 and SPIDER 2 with emphasis on the SPIDER 2 tests.

## INTRODUCTION

Debris produced from an explosion is categorized as primary or secondary. Primary fragmentation (e. g. fragmentation from the explosive device) is generally smaller with higher velocities. Secondary (e.g. structural debris, soil ejecta) is generally larger with lower velocities. Both categories of debris present a hazard to people and facilities in the vicinity of the explosion. So the question is “What is the hazard to people inside a structure that is impacted by debris from an explosion?”

The Science Panel Impact Debris Evaluation and Review (SPIDER) test program has been planned to develop improved predictions for the hazards inside an exposed site (ES) from fragments and debris. Data from the SPIDER tests include the mass and velocity required for perforation of the test cross-section (wall or roof section) and the characteristics of all debris, both primary and secondary, produced inside the ES. The SPIDER 1 test program completed in 2004 tested the hazard from high-angle spherical debris striking typical roof sections at terminal velocity. The SPIDER 2 test program conducted in 2009 was designed to determine the effect of spherical debris and fragments impacting wall cross-sections at higher than terminal velocity. The SPIDER 3 and SPIDER 4 test programs, which have not yet been conducted, are designed to test the hazard from high-angle cylindrical impactors striking roof sections at terminal velocity and from low-angle cylindrical impactors striking wall sections at higher than terminal velocity, respectively. Table 1 shows a summary of the entire SPIDER program.

In both SPIDER 1 and 2 test programs, the roof or wall response (e.g. penetration, deformation, spalling, breaching, perforation) to variable masses and velocities of spherical steel and concrete impactors was observed. Impact velocity and residual velocity of perforating fragments and ES debris were measured for each test for future use.

The SPIDER 1 test program is summarized and the SPIDER 2 test program is detailed including target wall and impactor designs. Test results are presented as well as analyses of these results. Recommendations are made for revisions to the Safety Assessment For Explosives Risk (*SAFER*) predicted kinetic energies required to perforate a given target type ($\Delta KE_n$) (TP 14, 2009) values for the wall types tested.

Table 1 – SPIDER Program Summary

| TEST VARIABLE | | SPIDER | | | |
|---|---|---|---|---|---|
| **(General)** | **(Specific)** | **1** | **2** | **3** | **4** |
| Spherical Impactors | Steel Ball | X | X | | |
| | Concrete Ball | X | X | | |
| Cylindrical Impactors | Steel Rod | | | X | X |
| | Concrete Rod | | | X | X |
| Roof Targets | Plywood Panel | X | | X | |
| | 4" (101.6mm) Reinforced Concrete | X | | X | |
| | 22 gauge Corrugated Metal Panel | X | | X | |
| Wall Targets | 5.5" (139.7mm) Reinforced Concrete | | X | | X |
| | 22-gauge Corrugated Metal Panel | | X | | X |
| | 8" (203.2mm) CMU-Reinforced & Grouted | | X | | X |
| | 8" (203.2mm) CMU-Unreinforced and Ungrouted | | X | | X |
| Impact Angle | Perpendicular Impacts | X | X | X | X |
| | Non-Perpendicular Impacts | | | | |
| Impact Location | Mid-Panel Impacts | X | X | X | X |
| | Quarter-point Panel Impacts | | | | |
| | Panel Edge Impacts | | | | |
| Impact Velocity | Terminal Velocity | X | | X | |
| | Higher-than-Terminal Velocity | | X | | X |

**SPIDER 1 TEST PROGRAM**

SPIDER 1 was designed as a series of shots firing impactors at roof targets (SPIDER, 2005). The shots were fired at terminal velocity with a known mass (steel or concrete impactor), achieving a predetermined kinetic energy (KE) goal based on *SAFER*'s predictions of the KE required to perforate the roof of an ES. Spherical impactors were used to ensure that the orientation of the debris did not affect the results.

Three types of roofs were used representing common roof construction and types used in *SAFER* (TP 19, 2009).

– Reinforced Concrete Roof: 4" (102mm) thick, one-way, simply supported 8' x 8' (2.44m x 2.44m), 3000 psi (20.7 MPa) reinforced concrete slab; #3 – 60 ksi (414 MPa) rebar on 10" (254mm) centers, each way, with 0.75" (19mm) bottom cover.

– Panelized Wood Roof: 8' x 8' (2.44m x 2.44m) section with 0.5" (12.7mm) CDX plywood sheathing on 2" x 6" (51mm x 152mm) wood joists at 24" (610mm) spacing. Minimum 4" x 8" (102mm x 203mm) beams support the roof joists. Typical nailing, steel connectors, and built-up roofing materials were used.

– Corrugated Steel Panel: 22 Gauge Verco HSB36 Corrugated Steel Panel. The 12' (3.66m) steel panels spanned one way over typical 8" x 2.5" x 14 gauge (203mm

x 64mm x 14 gauge) steel channels at 5’ (1.5m) (nominal) spacing. The valleys of the corrugated steel panel were bolted to the flange of each of the three supports.

Impactor masses were chosen based on the then-current *SAFER* predictions of the KE required to perforate the chosen target(s). This value is known as the $\Delta KE_n$ value in *SAFER* and is stored by roof or wall type. Table 2 shows the $\Delta KE_n$ values from Revision 3 of TP 14, 2007.

Table 2 – *SAFER* Parameters for Kinetic Energy Absorbed by Exposed Site Components, $\Delta KE_n$ (TP 14, 2007)

| | **KE Absorbed by Roof or Wall, $\Delta KE_n$** | |
|---|---|---|
| **ES Roof Types** | **ft-lb** | **Joules** |
| 4" (101.6mm) Reinforced Concrete | 10,000 | 13,560 |
| Plywood and Wood Joist | 300 | 406.8 |
| Light Metal Deck (22 gauge) | 500 | 678 |
| **ES Wall Types** | | |
| 6" (152.4mm) Reinforced Concrete Tilt-up | 37,500 | 50,850 |
| Corrugated Steel | 500 | 678 |
| Unreinforced Masonry | 4,500 | 6102 |
| 8" (203.2mm) Reinforced Masonry | 15,000 | 20,340 |

Impactors were launched from a Davis gun (breechless powder gun). Each impactor was placed in a lightweight plastic sabot prior to launch to obtain the projectile diameter required by the Davis gun. The sabot was stripped away from the impactor (in flight) prior to impact with the target roof.

The term “perforation” is used to indicate that the entire impactor passed through the target, whereas “penetration” refers to the impactor breaking the surface plane of the front face of the target (but not exiting through the rear face of the target). Impactor penetration (into the panel thickness) does not realistically occur in the thin plywood and steel panels. Response was photographed and described and the impact and residual velocities (when perforation occurred) of the steel and concrete impactors were also measured.

SPIDER 1 results are summarized in Table 3. The minimum KE is the highest KE that did not result in perforation while the maximum KE is the lowest KE that did result in perforation. Figure 1 shows the front and back faces of the 4” concrete target at threshold (entire impactor did not exit the back face of the wall) kinetic energy for a 13.1 lb (5.94 kg) concrete impactor.

Table 3 – SPIDER 1 Results Summary

| Roof | Impactor | Perforation KE (ft-lb) | | Perforation KE (Joules) | |
|---|---|---|---|---|---|
| | | Min (No Perf) | Max (Perf) | Min (No Perf) | Max (Perf) |
| 4" (102mm) Reinforced Concrete | Concrete | 9,091 | 20,830 | 12,326 | 28,242 |
| | Steel | 6,900 | 8,727 | 9,355 | 11,832 |
| 0.5" (13mm) Plywood | Concrete | 136 | 225 | 184 | 305 |
| | Steel | 40 | 115 | 54 | 156 |
| 22 Gauge Corrugated Steel | Concrete | 2,260 | 3,576 | 3,064 | 4,848 |
| | Steel | 1,000 | 1,215 | 1,356 | 1,647 |
| Note: Gray shading means threshold perforation obtained (entire impactor did not pass through target). | | | | | |

Front Face Back Face

Figure 1 – Concrete Impactor on Concrete Target at Threshold KE (20,830 ft-lbs/ 28,242 Joules)

The *SAFER* predictions of the KE required to perforate the roof types tested in the SPIDER 1 test program (see Table 2) were compared to the observed KE values shown in Table 3. As a result, the *SAFER* $\Delta KE_n$ values were changed in the TP 14 as shown in Table 4 (TP 14, 2009).

Table 4 – *SAFER* Parameters for Kinetic Energy Absorbed by Exposed Site Roof Components, $\Delta KE_n$ (TP 14, 2009)

| ES Roof Types | KE Absorbed by Roof, $\Delta KE_n$ | |
|---|---|---|
| | **ft-lb** | **Joules** |
| 4" (101.6mm) Reinforced Concrete | 10,000 | 13,560 |
| Plywood/Wood Joist (2x10 @ 16" (406.4mm)) | 50 | 67.8 |
| Plywood Panelized (2x6 @24" (609.6mm)) | 50 | 67.8 |
| Light Steel Panel (22 gauge) | 1000 | 1356 |

## SPIDER 2 TEST PROGRAM

SPIDER 2 was designed as a series of shots firing spherical steel and concrete impactors at various wall targets at velocities consistent with debris and primary fragments at low launch angles. A trajectory analysis was used to choose SPIDER 2 steel and concrete impactor characteristics that are consistent with the masses, initial potential explosion site (PES) debris velocities (< 3000 fps), and low launch angles (< 15$^o$) that can critically impact walls located between 500 to 3000 ft from the PES. Primary steel fragments, with initial velocities of < 5000 fps, were also included in the trajectory analysis.

### Target Wall Designs

Three wall targets were used for SPIDER 2 tests. Each represents a common ES wall construction in *SAFER*. The concrete masonry unit (CMU) wall was used to test perforation resistance of both the unreinforced, ungrouted cells and the reinforced, grouted cells.

- Reinforced Concrete Wall Design**:** Nominally 9' x 9' (2.74m x 2.74m), 5.5" (140mm) thick, 1-way simply supported, 4000 psi (27.6 MPa) ($f_c$') reinforced concrete slab with #5 - 60 ksi (414 MPa) rebar on 16" (406mm) centers, each way, centered within the slab depth. This reinforced concrete section was tested in SciPan 1 and 2, for its response to the blast overpressure loads, and represents the high-bay tilt-up ES model in *SAFER*. Rebar starts at 6" (152mm) from edges (free edge and edge of channel support, top and bottom) and provides 36 - 16" x 16" (406mm x 406mm) square targets framed by the rebar.
- Corrugated Steel Panel**:** The 22 Gauge Verco HSB-36 Corrugated Steel Panel is representative of all metal siding ES buildings in *SAFER*. The 12 ft (3.66m) steel panels span one way over typical 8" x 2.5" x 14 gauge (203mm x 64mm x 14 gauge) steel channels at 5.0 ft (1.5m) (nominal) spacing. The valleys of the corrugated steel panel are secured to the flange of each of the three supports.
- Reinforced Type A CMU Wall: This CMU wall consists of 8" x 8" x 16" (203mm x 203mm x 406mm) standard lightweight CMU in a running bond, with #4 – 60ksi (414 MPa) vertical rebar @ 24" (610mm) (every third cell). This slab is used primarily for testing impact on the unreinforced, ungrouted cells and for at least two tests on

reinforced, grouted cells. The wall is 6'8" (2.03m) wide x 8' (2.4m) tall with the outside vertical cores reinforced.

– Reinforced Type B CMU Wall: This CMU wall consists of 8" x 8" x 16" (203mm x 203mm x 406mm) standard lightweight CMU in a running bond, with #4 – 60ksi (414 MPa) vertical rebar @ 16" (406mm) (every other cell). This slab will be used primarily to conduct the reinforced, grouted cell tests. The wall is 8' (2.4m) wide x 8' (2.4m) tall with the outside vertical cores reinforced.

**Debris and Fragment Impactor Designs**

Spherical impactors were used to insure that the orientation of the debris on impact did not affect results. The concrete spheres had a strength, $f_c'$, at least 1000 psi (6.89 MPa) greater than the concrete slab (nominally = 5000 psi (34.5 MPa)). Figure 2 shows various impactors in the sabots.


Figure 2 – Concrete (bottom row) and Steel (top and middle row) Impactors in Sabots

The sizes of the impactors were determined based on *SAFER* KE bins 3 through 7 (TP 14, 2009) and the average fragment mass corresponding to the average *SAFER* KE for each bin (see Table 5). Impactor weights were adjusted slightly depending on commercially available steel spheres and concrete spherical molds (see Table 6).

**Instrumentation**

Each test was recorded using two high-speed video cameras, one focused perpendicular to the line of flight and one focused on the rear of the wall that recorded debris on the backside of the wall. The camera focused perpendicular to the line of flight recorded the impactor flight and impact on the front face as well as debris on the backside of the wall. This camera was used to measure impact velocity and, when perforation occurred, to determine the residual velocity of the impactor and wall debris.

An accelerometer was attached to the wall near the aim point and used to measure impact velocity in conjunction with a break-wire fastened to the muzzle of the gun. Additionally, Doppler radar was used to measure impact velocity.

Table 5 – *SAFER* KE Bins and Corresponding Average Fragment Weights

| Material | *SAFER* KE Bin | *SAFER* KE Min (ft-lbs) | *SAFER* KE Avg (ft-lbs) | *SAFER* KE Max (ft-lbs) | Average Fragment Weight[1] (lbs) | *SAFER* KE Min (Joules) | *SAFER* KE Avg (Joules) | *SAFER* KE Max (Joules) | Average Fragment Weight[1] (kg) |
|---|---|---|---|---|---|---|---|---|---|
| Concrete | 7 | 100 | 173 | 300 | 0.420 | 136 | 235 | 407 | 0.191 |
| Concrete | 6 | 300 | 547 | 1,000 | 1.000 | 407 | 742 | 1,356 | 0.454 |
| Concrete | 5 | 1,000 | 1,700 | 3,000 | 2.380 | 1,356 | 2,305 | 4,067 | 1.080 |
| Concrete | 4 | 3,000 | 5,000 | 10,000 | 5.610 | 4,067 | 6,779 | 13,558 | 2.545 |
| Concrete | 3 | 10,000 | 17,000 | 30,000 | 13.400 | 13,558 | 23,049 | 40,675 | 6.078 |
| Steel | 7 | 100 | 173 | 300 | 0.199 | 136 | 235 | 407 | 0.090 |
| Steel | 6 | 300 | 547 | 1,000 | 0.473 | 407 | 742 | 1,356 | 0.215 |
| Steel | 5 | 1,000 | 1,700 | 3,000 | 1.130 | 1,356 | 2,305 | 4,067 | 0.513 |
| Steel | 4 | 3,000 | 5,000 | 10,000 | 2.660 | 4,067 | 6,779 | 13,558 | 1.207 |
| Steel | 3 | 10,000 | 17,000 | 30,000 | 6.340 | 13,558 | 23,049 | 40,675 | 2.876 |

[1]Note: Shape factors, drag coefficients based on the fragment material, and the average fragment mass are used to determine the terminal velocity for that fragment. The average SAFER KE for a particular SAFER KE bin represents the kinetic energy of the average fragment weight for that bin traveling at its determined terminal velocity.

Table 6 – Impactor Sizes

| Impactor | Material | Impactor Diameter (in) | Impactor Weight (lbs) | Impactor Diameter (mm) | Impactor Weight (kg) |
|---|---|---|---|---|---|
| C1 | Concrete | 2.25 | 0.51 | 57.15 | 0.23 |
| C2 | Concrete | 3 | 1.15 | 76.20 | 0.52 |
| C3 | Concrete | 3.75 | 2.2 | 95.25 | 1.00 |
| C4 | Concrete | 5 | 5.75 | 127.00 | 2.61 |
| C5 | Concrete | 7.4 | 17.4 | 187.96 | 7.89 |
| S1 | Steel | 1.125 | 0.2 | 28.575 | 0.09 |
| S2 | Steel | 1.5 | 0.5 | 38.10 | 0.23 |
| S3 | Steel | 1.875 | 1 | 47.625 | 0.45 |
| S4 | Steel | 2.5 | 2.298 | 63.50 | 1.042 |

**Testing**

SPIDER 2 tests were performed throughout the summer of 2009. Two different size gas guns were used to fire the wide range of impactor diameters shown in Table 6. Each impactor was placed in a polyurethane sabot (see Figure 2) prior to launch to obtain the projectile diameter required by the gas gun. The sabot was stripped from the impactor (in flight) prior to impact with the target wall. Impact velocities and results

(whether or not the impactor perforated the wall) were recorded.  Sizes of any hole or deformation on both the front and rear of the wall were measured.  If debris was expelled from the rear of the wall (spall), the total number of significant debris pieces landing beyond one wall height was catalogued and the weights and distances to the furthest piece of debris and the largest piece of debris were measured.  The front and the rear of the target were photographed after each test, as was the spall pattern. Figure 3 shows a typical wall setup.

Initial velocities were estimated using the impactor weight and the *SAFER* $\Delta KE_n$ values for the wall types tested.  Velocities were adjusted based on the results of a particular impactor size and velocity against a particular wall target.  For example, if the first test did not result in a perforation the velocity was increased until perforation was achieved. Conversely if the first test resulted in perforation the velocity was decreased until the wall was not perforated.  This was continued until the KE necessary to perforate the wall was bounded.  In certain cases, the number of impactors and sabots, limitations on velocities that could be achieved and/or undamaged wall targets limited this iterative process.

Figure 3 – Reinforced Concrete Wall Test Setup

**Test Results**

Test results for all wall and impactor types are summarized in Table 7.  No useful results were recorded for some shots due to testing errors such as misfires and impactor breakup by the sabot splitter.  These test shots (2, 22, 33, 36, 72, 73, and 74) are not included in this table.

Again, the term “perforation” is used to indicate that the entire impactor passed through the target, whereas “penetration” refers to the impactor breaking the surface plane of the front face of the target (but not exiting through the rear face of the target).  The

minimum KE is the highest KE that did not result in perforation while the maximum KE is the lowest KE that did result in perforation.

As was noted in the SPIDER 1 tests, the corrugated steel panels appear to be much more resistant to perforation than predicted. Looking at the structural response of these panels, it appears that the panels undergo a membrane action type of response with very large deflections allowing the panel to resist perforation, given that a tear in the panel is not initiated. Other times the impactor perforated the panel at a much smaller KE and the damage was very localized. This seemed to be dependent on where the impactor struck the panel along the corrugation pattern (valley, ridge or transition region) and where the impactor struck the panel with respect to the support. If a tear in the panel was initiated, the impactor would perforate cleanly with minimal reduction in velocity.

**Observed Wall Damage**
In addition to whether or not the impactor perforated the wall, it is of interest to note whether or not the impactor caused the wall to spall. Spall can be a hazard to personnel behind the wall. In no cases did the corrugated steel panel spall. However, spall was often significant off the rear of the reinforced concrete and the masonry walls. Table 8 shows the maximum KE at which no spall occurred and the minimum KE at which spall did occur.

It should be noted that in all tests the reinforced masonry cells produced spall and all of the concrete impactors caused the reinforced concrete wall to spall. The air gap in the unreinforced masonry cells resulted in some impacts which did not produce spall. Likewise some steel impactors did not cause spall of the reinforced concrete wall.

**Reinforced Concrete Wall**
Figure 4 shows the front and back of a reinforced concrete wall after perforation by a 2.5” (63.50mm) steel impactor.

**Corrugated Steel Panel Wall**
Figure 5 shows the front and back of a corrugated steel panel wall after impact (no perforation) by a 3” (76.20mm) concrete impactor.

**Reinforced CMU Wall**
Figure 6 shows the front and back of a CMU wall after impact (no perforation) of a 1.125” (28.58mm) steel impactor in an unreinforced, ungrouted cell. Figure 7 shows the front and back of a CMU wall after impact (no perforation) of a 5” (127.00mm) concrete impactor in a reinforced cell.

Table 7 – SPIDER 2 Test Results

| Shot | Wall[1] | Impactor | Perforated | Velocity (ft/sec) | Kinetic Energy (ft-lb) | Velocity (m/sec) | Kinetic Energy (Joules) |
|---|---|---|---|---|---|---|---|
| 44 | CMU A (HC) | C1 | No | 562.01 | 2501 | 171.30 | 3391 |
| 45 | CMU A (HC) | C1 | No | 583.79 | 2699 | 177.94 | 3659 |
| 46 | CMU A (HC) | C1 | No | 598.75 | 2839 | 182.50 | 3849 |
| 47 | CMU A (HC) | C1 | No | 687.83 | 3747 | 209.65 | 5080 |
| 50 | CMU A (HC) | C3 | No | 311.38 | 3312 | 94.91 | 4491 |
| 51 | CMU A (HC) | C3 | Yes | 387.40 | 5127 | 118.08 | 6951 |
| 49 | CMU A (HC) | C3 | Yes | 446.19 | 6801 | 136.00 | 9221 |
| 48 | CMU A (HC) | C3 | Yes | 466.53 | 7435 | 142.20 | 10081 |
| 37 | CMU A (HC) | S1 | No | 435.50 | 589 | 132.74 | 799 |
| 38 | CMU A (HC) | S1 | No | 583.07 | 1056 | 177.72 | 1431 |
| 39 | CMU A (HC) | S1 | No | 613.22 | 1168 | 186.91 | 1583 |
| 43 | CMU A (HC) | S3 | No | 344.49 | 1843 | 105.00 | 2498 |
| 42 | CMU A (HC) | S3 | Yes | 352.69 | 1932 | 107.50 | 2619 |
| 41 | CMU A (HC) | S3 | No | 362.86 | 2045 | 110.60 | 2772 |
| 40 | CMU A (HC) | S3 | Yes | 381.23 | 2257 | 116.20 | 3060 |
| 53 | CMU A (RC) | C4 | No | 459.32 | 18837 | 140.00 | 25539 |
| 54 | CMU A (RC) | C4 | Yes | 577.43 | 29770 | 176.00 | 40362 |
| 52 | CMU A (RC) | C4 | Yes | 663.38 | 39293 | 202.20 | 53274 |
| 55 | CMU A (RC) | C5 | Yes | 410.10 | 45441 | 125.00 | 61610 |
| 69 | CMU B (HC) | C1 | No | 730.71 | 4228 | 222.72 | 5733 |
| 70 | CMU B (HC) | C1 | No | 739.17 | 4327 | 225.30 | 5866 |
| 66 | CMU B (HC) | S3 | Yes | 344.49 | 1843 | 105.00 | 2498 |
| 68 | CMU B (HC) | S3 | Yes | 387.14 | 2327 | 118.00 | 3155 |
| 67 | CMU B (HC) | S3 | Yes | 405.02 | 2547 | 123.45 | 3454 |
| 57 | CMU B (RC) | C4 | Yes | 515.09 | 23689 | 157.00 | 32118 |
| 58 | CMU B (RC) | C4 | No | 532.15 | 25284 | 162.20 | 34281 |
| 77 | CMU B (RC) | C5 | No | 230.31 | 14332 | 70.20 | 19432 |
| 76 | CMU B (RC) | C5 | Partial | 278.48 | 20953 | 84.88 | 28408 |
| 60 | CMU B (RC) | C5 | Yes | 351.54 | 33390 | 107.15 | 45271 |
| 61 | CMU B (RC) | S4 | No | 626.64 | 14012 | 191.00 | 18998 |
| 71 | CMU B (RC) | S4 | Yes | 716.47 | 18317 | 218.38 | 24835 |
| 62 | CMU B (RC) | S4 | Yes | 807.08 | 23244 | 246.00 | 31514 |
| 75 | CMU B (RC) | S5 | Yes | 409.12 | 15275 | 124.70 | 20710 |
| 59 | CMU B (RC) | S5 | Yes | 459.32 | 19253 | 140.00 | 26103 |
| 56 | CMU B (RC) | S5 | Yes | 467.52 | 19947 | 142.50 | 27044 |

Notes: [1] HC refers to unreinforced (“hollow”) cells and RC refers to reinforced cells in the CMU walls

Table 7 – SPIDER 2 Test Results (Continued)

| Shot | Wall[1] | Impactor | Perforated | Velocity (ft/sec) | Kinetic Energy (ft-lb) | Velocity (m/sec) | Kinetic Energy (Joules) |
|---|---|---|---|---|---|---|---|
| 25 | Concrete | C4 | No | 669.78 | 40054 | 204.15 | 54306 |
| 26 | Concrete | C4 | No | 761.87 | 51826 | 232.22 | 70267 |
| 27 | Concrete | C4 | No | 1016.86 | 92322 | 309.94 | 125172 |
| 30 | Concrete | C5 | No | 484.71 | 63479 | 147.74 | 86065 |
| 32 | Concrete | C5 | No | 520.67 | 73246 | 158.70 | 99309 |
| 31 | Concrete | C5 | Yes | 548.49 | 81283 | 167.18 | 110205 |
| 28 | Concrete | C5 | Yes | 638.42 | 110121 | 194.59 | 149305 |
| 3 | Concrete | S4 | No | 583.99 | 12169 | 178.00 | 16500 |
| 4 | Concrete | S4 | No | 666.01 | 15828 | 203.00 | 21460 |
| 5 | Concrete | S4 | No | 741.80 | 19635 | 226.10 | 26622 |
| 80 | Concrete | S4 | Yes | 847.96 | 25658 | 258.46 | 34787 |
| 1 | Concrete | S4 | Yes | 948.16 | 32079 | 289.00 | 43494 |
| 13 | Concrete | S5 | No | 383.53 | 13424 | 116.90 | 18200 |
| 29 | Concrete | S5 | No | 520.08 | 24683 | 158.52 | 33466 |
| 14 | Concrete | S5 | Yes | 533.13 | 25938 | 162.50 | 35168 |
| 12 | Concrete | S5 | Yes | 591.21 | 31897 | 180.20 | 43246 |
| 34 | Steel | C2 | No | 171.42 | 525 | 52.25 | 711 |
| 79 | Steel | C2 | Yes | 254.20 | 1154 | 77.48 | 1564 |
| 35 | Steel | C2 | No | 341.83 | 2087 | 104.19 | 2829 |
| 65 | Steel | C2 | Yes | 380.58 | 2586 | 116.00 | 3507 |
| 64 | Steel | C2 | Yes | 426.51 | 3248 | 130.00 | 4404 |
| 63 | Steel | C2 | Yes | 557.74 | 5555 | 170.00 | 7531 |
| 20 | Steel | C4 | No | 175.52 | 2751 | 53.50 | 3730 |
| 23 | Steel | C4 | No | 228.02 | 4642 | 69.50 | 6294 |
| 21 | Steel | C4 | Yes | 278.77 | 6939 | 84.97 | 9408 |
| 78 | Steel | C4 | No | 284.22 | 7213 | 86.63 | 9779 |
| 24 | Steel | C4 | Yes | 297.90 | 7924 | 90.80 | 10743 |
| 10 | Steel | S2 | No | 319.55 | 793 | 97.40 | 1075 |
| 9 | Steel | S2 | Yes | 351.38 | 959 | 107.10 | 1300 |
| 6 | Steel | S2 | No | 361.55 | 1015 | 110.20 | 1376 |
| 8 | Steel | S2 | Yes | 370.73 | 1067 | 113.00 | 1447 |
| 7 | Steel | S2 | Yes | 457.02 | 1622 | 139.30 | 2199 |

Notes: [1] HC refers to unreinforced (“hollow”) cells and RC refers to reinforced cells in the CMU walls

Table 7 – SPIDER 2 Test Results (Continued)

| Shot | Wall | Impactor | Perforated | Velocity (ft/sec) | Kinetic Energy (ft-lb) | Velocity (m/sec) | Kinetic Energy (Joules) |
|---|---|---|---|---|---|---|---|
| 11 | Steel | S4 | No | 232.94 | 1936 | 71.00 | 2625 |
| 17 | Steel | S4 | Yes | 259.97 | 2412 | 79.24 | 3270 |
| 19 | Steel | S4 | No | 267.39 | 2551 | 81.50 | 3459 |
| 18 | Steel | S4 | Yes | 270.08 | 2603 | 82.32 | 3529 |
| 16 | Steel | S4 | Yes | 270.34 | 2608 | 82.40 | 3536 |
| 15 | Steel | S4 | No | 274.67 | 2692 | 83.72 | 3650 |

Notes: [1] HC refers to unreinforced ("hollow") cells and RC refers to reinforced cells in the CMU walls

Table 8 – Kinetic Energies at which Impactors Caused Spall

| Target | Impactor | Max. KE (ft-lbs) w/o Spall | Min. KE (ft-lbs) w/ Spall | Max. KE (Joules) w/o Spall | Min. KE (Joules) w/ Spall |
|---|---|---|---|---|---|
| Reinforced Concrete | Concrete | N/A | 40,054 | N/A | 54,306 |
| Reinforced Concrete | Steel | 12,169 | 13,424 | 16,500 | 18,200 |
| Unreinforced Masonry | Concrete | 4,327 | 5,127 | 5,866 | 6,951 |
| Unreinforced Masonry | Steel | 589 | 1,056 | 799 | 1,431 |
| Reinforced Masonry | Concrete | N/A | 18,837 | N/A | 25,539 |
| Reinforced Masonry | Steel | N/A | 14,012 | N/A | 18,998 |
| Note: Gray shading means all impactors caused spall. | | | | | |

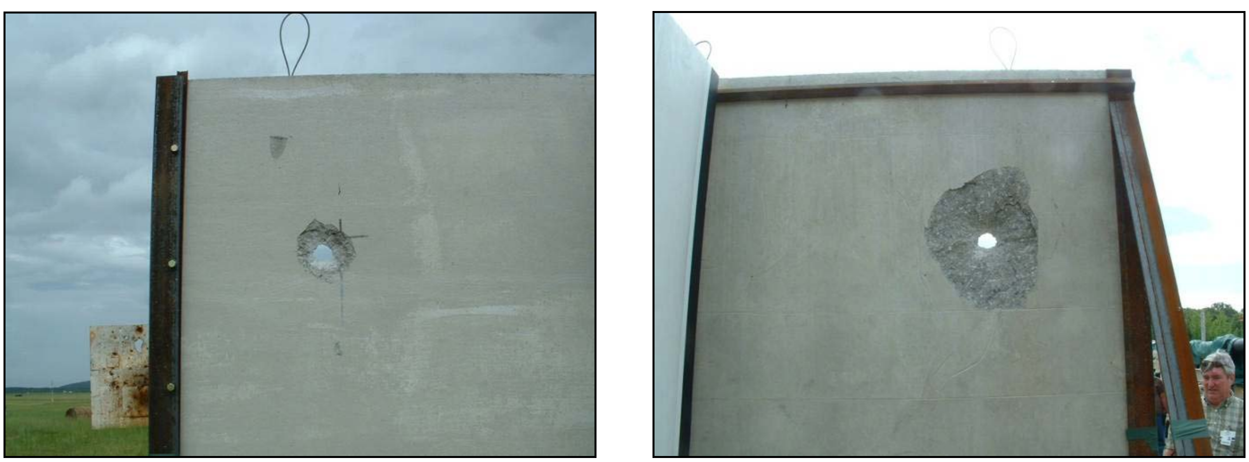

Figure 4 – Front (left) and Back (right) of Reinforced Concrete Wall After 2.5" (63.50mm) Steel Impactor Perforation


Figure 5 – Front (left) and Back (right) of Corrugated Steel Panel After Impact (No Perforation) by 3" (76.20mm) Concrete Impactor


Figure 6 – Front (left) and Back (right) of CMU Wall After Impact (No Perforation) by 1.125" (28.58mm) Steel Impactor on Unreinforced Cell


Figure 7 – Front (left) and Back (right) of CMU Wall After Impact (No Perforation) by 5" (127.00mm) Concrete Impactor on Reinforced Cell

## COMPARISON OF TEST RESULTS TO PREDICTED RESULTS

### Comparison to *SAFER* Threshold Kinetic Energies

The threshold kinetic energies ($\Delta KE_n$) at which debris will begin to perforate the wall used by *SAFER* (TP 14, 2009) were used as baseline predictions for the SPIDER 2 tests. Table 9 shows a comparison of the *SAFER* $\Delta KE_n$ to the observed minimum and maximum perforation KEs. For Table 9 the minimum KE is the highest KE that did not result in perforation while the maximum KE is the lowest KE that did result in perforation.

It should be noted that the *SAFER* $\Delta KE_n$ shown for reinforced concrete is for a 6" (152.4mm) reinforced concrete tilt-up panel while the reinforced concrete panels tested were 5.5" (127mm) thick. While the *SAFER* $\Delta KE_n$ appears to be quite conservative for concrete impactors it may be unconservative for steel impactors.

The *SAFER* $\Delta KE_n$ for unreinforced masonry were in close agreement with the results for concrete impactors but unconservative for steel impactors. The *SAFER* $\Delta KE_n$ for reinforced masonry were in close agreement for steel impactors and slightly conservative for concrete impactors.

### Comparison of *SAFER* $\Delta KE_n$ with Other Predicted Threshold Kinetic Energies

The threshold kinetic energies of the steel impactors on a 5.5" (139.70mm) reinforced concrete wall and a 22 gauge steel panel were predicted using the methods described in DDESB Technical Paper 16 (TP 16, 2009). It should be noted that the TP 16 method is applicable to a flat steel plate not a corrugated steel panel. Table 10 shows the predictions for the 22 gauge steel panel and Table 11 shows the predictions for the reinforced concrete wall.

Additionally, LS-Dyna was used to predict the threshold kinetic energy for a 2.5" (63.50mm) steel impactor striking a 5.5" (139.70mm) reinforced concrete wall (the *SAFER* $\Delta KE_n$ is for a 6" (152.4mm) reinforced concrete wall). The LS-Dyna prediction is shown in Table 11.

Comparing the TP 16 predicted threshold kinetic energies with the observed kinetic energies shown in Table 9, the TP 16 methodology is overly conservative for the 22 gauge steel panel. As discussed above, in some cases the corrugated steel panels appear to undergo a membrane action response with very large deflections without perforation while at other times the damage was very localized and seemed to depend on whether the impactor struck the panel on the ridge, valley or transition region of the corrugation.

Comparing the test results for the 5.5" (139.70mm) reinforced concrete wall with the predicted threshold kinetic energies using TP 16 methods, the TP 16 method (27,658 ft-lbs or 37,499 Joules) is unconservative for impactor S4 compared to between 19,635 and 25,658 ft-lbs (26,622 – 34,787 Joules) observed. However, the TP 16 method is overly conservative (5,590 ft-lbs or 7,579 Joules) when compared to the observed

results (24,683 – 25,938 ft-lbs or 33,466 – 35,168 Joules) for impactor S5. The LS-Dyna prediction (34,047 ft-lbs or 46,162 Joules) is also unconservative for impactor S4.

It should be noted that the LS-Dyna calculations were a very rough first attempt at modeling the reinforced concrete wall subject to the S4 steel impactor. The blind prediction was intended as an initial feasibility study of the capabilities of the model to accurately capture the penetration phenomenon and perforation thresholds of reinforced concrete slabs of finite thickness. Further refinement of the model is planned in conjunction with future SPIDER test series.

Table 9 – Summary of Results, Comparison of Predicted Kinetic Energies with Observed Kinetic Energies

| Target | Impactor | *SAFER* $\Delta KE_n$ (ft-lbs) | Observed Min. KE (ft-lbs) | Observed Max. KE (ft-lbs) | *SAFER* $\Delta KE_n$ (Joules) | Observed Min. KE (Joules) | Observed Max. KE (Joules) |
|---|---|---|---|---|---|---|---|
| Reinforced Concrete | Concrete | 37,500 | 73,246 | 81,283 | 50,843 | 99,309 | 110,205 |
| Reinforced Concrete | Steel | 37,500 | 24,683 | 25,658 | 50,843 | 33,466 | 34,787 |
| Corrugated Steel | Concrete | 500 | 4,642 | 1,154 | 678 | 6,294 | 1,564 |
| Corrugated Steel | Steel | 500 | 2,692 | 959 | 678 | 3,650 | 1,300 |
| Unreinforced Masonry | Concrete | 4,500 | 4,327 | 5,127 | 6,101 | 5,866 | 6,951 |
| Unreinforced Masonry | Steel | 4,500 | 2045[A] | 1,843 | 6,101 | 2,772 | 2,498 |
| Reinforced Masonry | Concrete | 15,000 | 18,837 | 20,953 | 20,337 | 25,539 | 28,408 |
| Reinforced Masonry | Steel | 15,000 | 14,012 | 15,275 | 20,337 | 18,998 | 20,710 |

[A]Impactor grazed web of masonry unit slowing it down as it passed through the unreinforced cell. Spall hole on back of wall indicates that impactor almost perforated.

Note: Gray shading means threshold perforation obtained (entire impactor did not pass through target).

Table 10 – Comparison of TP 16 and *SAFER* Threshold Kinetic Energies for 22 Gauge Steel Panels

| Steel Impactor Number | Predicted Threshold Kinetic Energy | | | |
|---|---|---|---|---|
| | *SAFER* $\Delta KE_n$ (ft-lbs) | DDESB TP 16 (ft-lbs) | *SAFER* $\Delta KE_n$ (Joules) | DDESB TP 16 (Joules) |
| S1 | 500 | 103 | 678 | 140 |
| S2 | 500 | 125 | 678 | 170 |
| S3 | 500 | 148 | 678 | 200 |
| S4 | 500 | 194 | 678 | 263 |
| S5 | 500 | 250 | 678 | 340 |

Table 11 – Comparison of TP 16, LS-Dyna and *SAFER* Threshold Kinetic Energies for Reinforced Concrete Walls

| Steel Impactor Number | Predicted Threshold Kinetic Energy | | | | | |
|---|---|---|---|---|---|---|
| | *SAFER* $\Delta KE_n$ (ft-lbs) | DDESB TP 16 (ft-lbs) | LS-Dyna (ft-lbs) | *SAFER* $\Delta KE_n$ (Joules) | DDESB TP 16 (Joules) | LS-Dyna (Joules) |
| S1 | 37,500 | 50,681 | - | 50,843 | 68,714 | - |
| S2 | 37,500 | 59,431 | - | 50,843 | 80,577 | - |
| S3 | 37,500 | 52,062 | - | 50,843 | 70,587 | - |
| S4 | 37,500 | 27,658 | 34,047 | 50,843 | 37,499 | 46,162 |
| S5 | 37,500 | 5,590 | - | 50,843 | 7,579 | - |

**Conclusions and Recommendations**

The SPIDER 2 testing has shown that the *SAFER* $\Delta KE_n$ values are

- in close agreement with the observed values for concrete impactors on unreinforced masonry and steel impactors on reinforced masonry
- slightly conservative for concrete impactors on reinforced masonry
- conservative for concrete and steel impactors on corrugated steel
- unconservative for steel impactors on unreinforced masonry
- unconservative for concrete and steel impactors on reinforced concrete (note: *SAFER* $\Delta KE_n$ is for 6" (152.40mm) reinforced concrete rather than the 5.5" (139.70mm) reinforced concrete tested)

Although, as yet no decisions have been made based on the SPIDER 2 results, they will likely lead to changes in the *SAFER* $\Delta KE_n$ for reinforced concrete tilt-up, corrugated steel, and unreinforced masonry walls in future versions of *SAFER*. Corroborating the results from SPIDER 1, the impactor material type has a strong influence on target perforation; therefore, future versions of *SAFER* will need to have separate $\Delta KE_n$ values for different impactor materials.

It is not necessary for debris impacting walls to perforate the walls to result in hazards to personnel on the other side of the wall. Spall from the back of the wall may present a hazard. Additionally, the impacting debris may break up resulting in more pieces of debris on the back side of the wall and, in reality, an explosion would result in multiple pieces of debris impacting the exposed structure which was not characterized in the tests where only a single piece of debris impacted the structure at one time.

**Future Testing**

SPIDER 1 and 2 utilized spherical impactors. Future test series (SPIDER 3 and 4) will be similar to the SPIDER 1 and 2 test series using cylindrical impactors. The goal of these tests is to eventually develop perforation prediction models based on either unit kinetic energy or as a function of mass and velocity as independent variables. The impactors will be steel and concrete cylinder with length-to-diameter ratios of 2 and 10.

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# RESPONSE OF TYPICAL WALL PANELS TO DEBRIS AND FRAGMENT IMPACT

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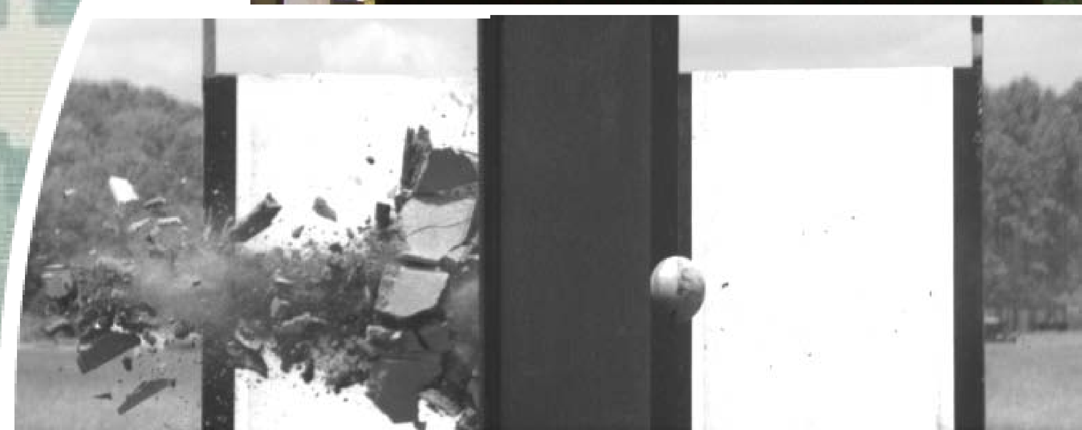
**John Tatom –** APT Research, Inc

**Robert Conway –** Naval Facilities Engineering Service Center

**34th DoD Explosives Safety Seminar**
**Portland, OR**
**14 July 2010**

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  - Mr. Michael Swisdak
  - Ms. Lea Ann Cotton
- Mr. Jesse Davis, APT Research, Inc.
- Mr. Youssef Ibrahim, NAVFAC ESC

# Outline

- Introduction
  - ►SPIDER Program Overall
  - ►SPIDER 1 Test Program
- SPIDER 2 Testing
- Results
- Comparison of Test Results & Predictions
- Conclusions and Recommendations

# Purpose of SPIDER Test Programs

- To develop improved predictions for the hazards inside an exposed site (ES) from fragments and debris
  - SPIDER 1 – spherical impactors striking roof targets at terminal velocity (completed)
  - SPIDER 2 – spherical impactors striking wall targets at greater than terminal velocity (completed)
  - SPIDER 3 – cylindrical impactors striking roof targets at terminal velocity (planned)
  - SPIDER 4 – cylindrical impactors striking wall targets at greater than terminal velocity (planned)

# SPIDER 1 Test Program Summary (1 of 2)

- Roof Types
  - 4” thick, 3000 psi, simply supported, one way reinforced concrete slab with #3 bars @ 10” on center, each way
  - ½” plywood sheathing on 2” x 6” wood joists @ 24” on center
  - 22 gauge corrugated steel panels, one way with supports at 5’ on center
- Approximate Spherical Impactor Weights(lbs)
  - Steel – 0.15, 0.18, 0.34, 0.38, 0.42, 0.75, 0.8, 2.4, 4,15, 4.3, 5.6
  - Concrete – 0.7, 0.9, 0.95, 1.5, 2.0, 2.8, 3.9, 9.25, 9.6, 13.1, 21.8

# SPIDER 1 Test Program Summary (2 of 2)

## Results

| Target | Impactor | SAFER $\Delta KE_n$ (ft-lbs) | Observed Test Results: Largest Non-Perforating KE (ft-lbs) | Observed Test Results: Smallest Perforating KE (ft-lbs) |
|---|---|---|---|---|
| Concrete | Concrete | 10,000 | 9,091 | 20,830 |
| | Steel | 10,000 | 6,900 | 8,727 |
| Plywood | Concrete | 300 - 600 | 136 | 225 |
| | Steel | 300 - 600 | 40 | 115 |
| Corrugated Steel | Concrete | 500 | 2,260 | 3,576 |
| | Steel | 500 | 1,000 | 1,215 |

# Proposed Changes to SAFER $\Delta KE_n$ Roof Values

| | $\Delta KE_n$ (ft-lb) | | |
|---|---|---|---|
| | SAFER 3 | SAFER 3+ | |
| Exposed Site Roof Type | All Fragments | Steel | Concrete |
| 4” Reinforced Concrete | 10,000 | 10,000 | 20,000 |
| 5/8” Plywood/Wood Joist | 300 | 50 | 150 |
| Lightweight Metal Deck | 500 | 1,000 | 3,000 |

# SPIDER 2 Target Walls

- 5.5” thick, 4000 psi, simply supported, one way reinforced concrete slab with #5 bars @ 16” on center, each way
- 22 gauge corrugated steel panels, one way with supports at 5’ on center
- 8” x 8” x 16” lightweight CMU, running bond w/ #4 vertical rebar @ 24” on center (CMU Type A Wall)
- 8” x 8” x 16” lightweight CMU, running bond w/ #4 vertical rebar @ 16” on center (CMU Type B Wall)

# SPIDER 2 Spherical Impactors

| Impactor | Material | Impactor Diameter (in) | Impactor Weight (lbs) |
|---|---|---|---|
| C1 | Concrete | 2.25 | 0.51 |
| C2 | Concrete | 3 | 1.15 |
| C3 | Concrete | 3.75 | 2.2 |
| C4 | Concrete | 5 | 5.75 |
| C5 | Concrete | 7.4 | 17.4 |
| S1 | Steel | 1.125 | 0.2 |
| S2 | Steel | 1.5 | 0.5 |
| S3 | Steel | 1.875 | 1 |
| S4 | Steel | 2.5 | 2.298 |
| S5 | Steel | 3.41 | 5.877 |


Concrete (bottom row) and Steel (top & middle row) Impactors in Sabots

Impactor Weight ~ Average Fragment Mass Corresponding to Average SAFER KE

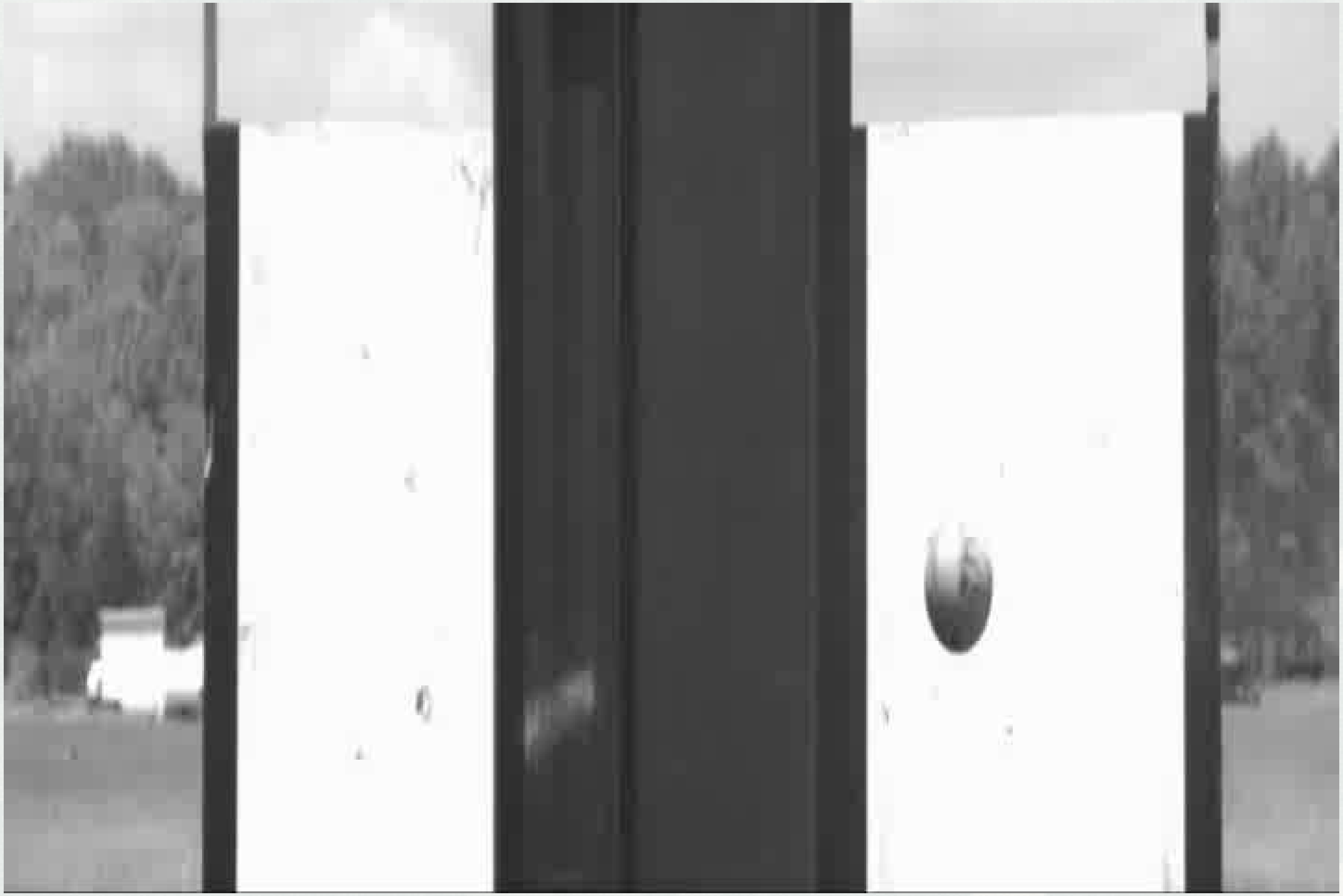
# Instrumentation

- 2 high-speed video cameras
  - Perpendicular to line of flight recording impactor flight, impact on front face & debris on backside – measured impact velocity & residual impactor & debris velocity
  - Focused on rear of wall recording debris on backside
- Accelerometer on wall near aim point measuring impact velocity in conjunction with break-wire at gun muzzle
- Doppler radar measuring impact velocity
- Still photos taken of front and backside of wall, debris field and significant debris after each shot

# Testing

- 2 sizes of gas guns used
- Initial velocities estimated using impactor weights & SAFER $\Delta KE_n$ for wall type
- Velocities adjusted based on results of previous test(s) until $\Delta KE_n$ was bounded
- Polyurethane sabot stripped from impactor at gun muzzle
- Impact velocities & perforation results recorded
- Spall – total number of significant debris pieces landing beyond one wall height, weights & distances to furthest debris and largest debris measured

# Concrete Impactor Perforating Reinforced CMU Cell



# Typical Wall Responses

# Perforation of RC Wall by 2.5” Steel Impactor

Front

Back

# No Perforation of Steel Wall by 3” Concrete Impactor


Front

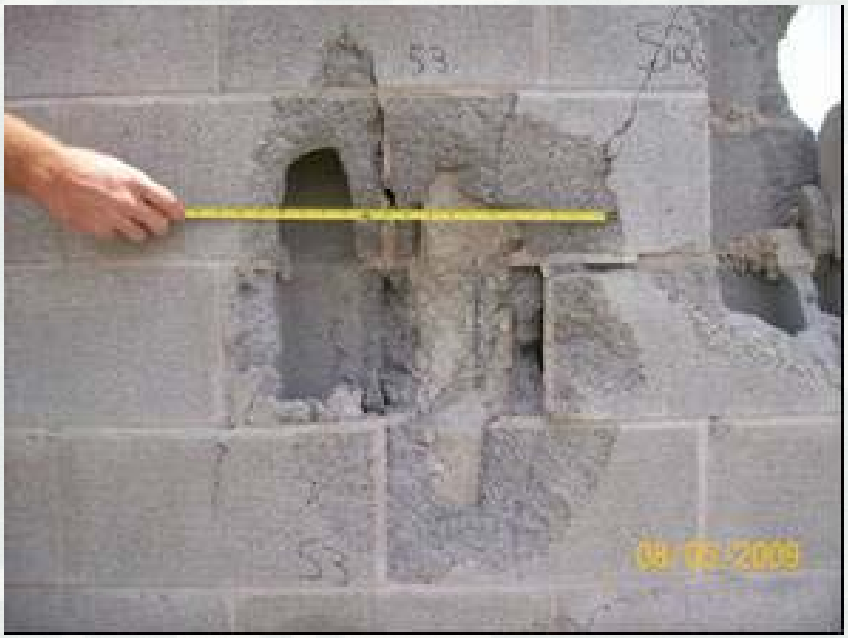

Back

# No Perforation of Unreinforced CMU by 1.125” Steel Impactor


Front


Back

# No Perforation of Reinforced CMU by 5” Concrete Impactor

Front

Back

# SPIDER 2 Test Results Compared to SAFER $\Delta KE_n$

| Target | Impactor | *SAFER* $\Delta KE_n$ (ft-lbs) | Largest Non-Perforating KE (ft-lbs) | Smallest Perforating KE (ft-lbs) |
|---|---|---|---|---|
| Reinforced Concrete | Concrete | 37,500 | 73,246 | 81,283 |
| | Steel | 37,500 | 24,683 | 25,658 |
| Corrugated Steel | Concrete | 500 | 4,642 | 1,154 |
| | Steel | 500 | 2,692 | 959 |
| Unreinforced Masonry | Concrete | 4,500 | 4,327 | 5,127 |
| | Steel | 4,500 | 2045[A] | 1,843 |
| Reinforced Masonry | Concrete | 15,000 | 18,837 | 20,953 |
| | Steel | 15,000 | 14,012 | 15,275 |

[A]Impactor grazed web of masonry unit slowing it down as it passed through the unreinforced cell. Spall hole on back of wall indicates that impactor almost perforated.
Note: Gray shading means threshold perforation obtained.

# SAFER $\Delta KE_n$ vs. DDESB TP 16 & LS-Dyna Predictions

| Target | Steel Impactor Number | Predicted Threshold Kinetic Energy | | |
|---|---|---|---|---|
| | | *SAFER* $\Delta KE_n$ (ft-lbs) | DDESB TP 16 (ft-lbs) | LS-Dyna (ft-lbs) |
| Corrugated Steel | S1 | 500 | 103 | - |
| | S2 | 500 | 125 | - |
| | S3 | 500 | 148 | - |
| | S4 | 500 | 194 | - |
| | S5 | 500 | 250 | - |
| Reinforced Concrete | S1 | 37,500 | 50,681 | - |
| | S2 | 37,500 | 59,431 | - |
| | S3 | 37,500 | 52,062 | - |
| | S4 | 37,500 | 27,658 | 34,047 |
| | S5 | 37,500 | 5,590 | - |

# Conclusions (1 of 2)

- The SPIDER 2 testing has shown that the *SAFER* $\Delta KE_n$ values are
  - in close agreement w/ observed values for concrete impactors on unreinforced masonry & steel impactors on reinforced masonry
  - slightly conservative for concrete impactors on reinforced masonry
  - conservative for concrete & steel impactors on corrugated steel

# Conclusions (2 of 2)

- The SPIDER 2 testing has shown that the SAFER $\Delta KE_n$ values are
  - unconservative for steel impactors on unreinforced masonry
  - unconservative for concrete and steel impactors on reinforced concrete (note: SAFER $\Delta KE_n$ is for 6” (152.40mm) reinforced concrete rather than the 5.5” (139.70mm) reinforced concrete tested)

# Recommendations

- Recommend changing SAFER $\Delta KE_n$ values for:
  - Reinforced Concrete Roof & Walls
  - Corrugated Steel Roof & Walls
  - Plywood Roof
  - Reinforced & Unreinforced CMU Walls
- Designate separate SAFER $\Delta KE_n$ values for concrete and steel impactors

# Questions?